Baseline-and-Credit Emission Permit Trading: Experimental Evidence Under Variable Output Capacity*

Neil J. Buckley†, Stuart Mestelman and R. Andrew Muller‡

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Abstract

Two approaches to emissions trading are cap-and-trade, in which an aggregate cap on emissions is distributed in the form of allowance permits, and baseline-and-credit, in which firms earn emission reduction credits for emissions below their baselines. Theoretical considerations suggest the long-run equilibria of the two plans will differ if baselines are proportional to output, because a variable baseline is equivalent to an output subsidy. As a progressive step towards testing the full long-run model, this paper reports on a laboratory experiment designed to test the prediction under fixed emission rates and variable output capacity. A computerized environment has been created in which subjects representing firms choose output capacities under fixed emission technology and participate in markets for emission rights and for output. Demand for output is simulated. All decisions are tracked through a double-entry bookkeeping system. Our evidence supports the theoretical prediction that aggregate output and emissions are inefficiently high under a baseline-and-credit trading plan compared to a corresponding cap-and-trade plan.

JEL classification: C92, L50, Q58

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†Assistant Professor, York University

‡Professor and Professor, McMaster University

1 Introduction

Emissions trading is now well established as a method of regulating emissions of uniformly mixed pollutants. The classic analysis assumes that the regulatory authority sets an aggregate cap on emissions from a set of sources and then divides the cap into a number of tradable permits (frequently called allowances), each of which authorizes the discharge of a unit quantity of emissions. Although the allowances could be sold at auction to raise revenue, the most frequently discussed plans assume that the permits will be distributed to the regulated firms on some ad hoc basis. Firms then trade the allowances, establishing a market price. In equilibrium, individual firms choose emissions such that the marginal cost of abating pollution equals the allowance price. They redeem allowances equal to the emissions discharged, selling or banking the remainder. If emissions exceed the initial distribution of allowances the firm must purchase allowances to cover the excess. Such plans are generally known as *cap-and-trade* plans. A good example is the U.S. EPA's sulphur dioxide auction.

Many field implementations of emissions trading take a different approach. An example is the clean development mechanism proposed under the Kyoto Protocol. In these *baseline-and-credit* plans there is no explicit cap on aggregate emissions. Instead, each firm has the right to emit a certain baseline level of emissions. This baseline may be derived from historical emissions or from a performance standard that specifies the permitted ratio of emissions to output. Firms create emission reduction credits by emitting fewer than their baseline emissions. These credits may be banked or sold to firms who exceed their baselines. The effect is to limit aggregate emissions to an *implicit* cap equal to the sum of the individual baselines. Typical baseline-and-credit plans also differ from classic cap-and-trade in a number of institutional details. For example, credits are often computed on a project-by-project basis rather than on the basis of enterprise-wide emissions. They must be certified and registered before they can be traded and there are generally restrictions that credits cannot be registered until the emission reductions have actually occurred.

Baseline-and-credit plans are theoretically equivalent to a cap-and-trade plan if the cap implicit in the baseline-and-credit plan is fixed and numerically equal to the fixed cap in a cap-and-trade plan. In many cases, however, the baseline is computed by multiplying a measure of firm scale (energy input or product output) by a performance standard specifying a required ratio of emissions to input or output.[1] In this case, the implicit cap on aggregate emissions varies with the level of aggregate output. Fischer (2001, 2003) refers to such plans as tradable performance standards.

The variable baseline in a baseline-and-credit plan introduces a critical difference in long-run performance compared to cap-and-trade with the same implied performance standard.[2] Specifically, the variable baseline acts as a subsidy on output. Firms receiving this subsidy will tend to expand their capacity to produce output. This introduces two potential inefficiencies. If the performance standard remains the same in both plans, the baseline-and-credit plan will exhibit higher output, emissions, and external costs. If, instead, the performance standard under baseline-and-credit is tightened so as

[1]This ratio is generally called the *emission intensity*.

[2]A cap-and-trade plan with aggregate cap on emissions may be said to imply a performance standard of $r^s = E/Q$ where E and Q are respectively aggregate emissions and output in long run equilibrium.

to meet the aggregate emissions specified under cap-and-trade, then industry costs will increase due to unnecessarily tight restrictions on emitting firms (Muller 1999; Dewees 2001; Fischer, 2001, 2003). It should be noted that this reasoning presumes that firms are adjusting to pollution regulation on two margins: the emission intensity of output and the level of output itself. Moreover the reasoning is essentially long-run in that output is changed by firms' investing or divesting themselves of productive capacity and equilibrium is computed by imposing a zero-profit restriction on firms in the market.

Currently, both cap-and-trade and baseline-and-credit plans are being implemented at similar rates at the international level (Hasselknippe 2003). However, the predictions on the relative performance of baseline-and-credit versus cap-and-trade have not been tested in the laboratory. Thus far, experiments have been fruitful in shaping cap-and-trade public policy (Cason 1995; Cason and Plott 1996), but as of yet no baseline-and-credit laboratory studies have been published. Laboratory implementation of baseline-and-credit trading would serve several goals: it would verify that market processes are sufficient to drive agents to competitive equilibrium, demonstrate the contrast between baseline-and-credit and cap-and-trade to policy makers, and possibly create a vehicle for training policy-makers and practitioners in the nature of alternative emission trading plans.

We have undertaken a long-term research project to compare the properties of baseline-and-credit and cap-and-trade plans in the lab. In previous work (Buckley, Muller, and Mestelman 2003) we have developed a tractable model with constant returns to scale in production and multiple firm types. We have implemented a computerized lab environment with explicit capacity and emission intensity decision, fully specified markets for emission rights and output, and a complete accounting framework. We have demonstrated that predicted results hold in simulated markets with robot traders adjusting on both the output and emissions intensity margins. However, market instability occurs when capacity is freely adjustable, so we have implemented work with human subjects slowly, examining the emissions intensity margin and the output market margin one at a time.

Buckley (2004) reports on six sessions comparing baseline-and-credit with cap-and-trade when firm capacities are fixed and firm adjustment is limited to emission intensity. The investigation seeks to confirm the prediction that the outcome of the two approaches would be the same when the output subsidy inherent to the baseline-and-credit plan can not possibly lead to productive expansion. Any deviation from parallel results could be then laid to the institutional differences between the two plans rather than the implied subsidy on output and emissions. The study confirms that the overall predictions on emissions hold. Efficiency in the market was improved, although only about one-half the available gains from trade were realized. However there were some deviations from the benchmark values computed under the assumption of perfectly competitive equilibrium. Emission permit prices were higher under baseline-and-credit trading and inventories of permits were irrationally high in both treatments.

In this paper we investigate the complementary problem of adjustment on the capacity margin. That is, we hold emission intensity constant at the optimal level for each type of firm and allow firms to increase or reduce their productive capacity each decision period. We have two objectives. First we wish to see whether market forces are sufficiently strong as to generate and maintain a competitive equilibrium. Secondly, we are particularly interested in demonstrating that the baseline-and-credit policy leads to higher emissions and output than occur under cap-and-trade.

2 Methods

We ran six laboratory sessions (three cap-and-trade and three baseline-and-credit), each involving 8 subjects, in September and October of 2004. All subjects had completed an introductory course in economics. Subjects were recruited from the general population of undergraduates at McMaster University. Sessions lasted approximately three hours. For the first hour and a half, students received instruction and participated in 4 training periods using an alternate set of parameters. This training period was rewarded by a flat fee of $10. Subjects then took a short break and returned to participate in 10 paid rounds using the parameters reported here. After 10 rounds they were informed of their results and paid privately in cash. Subjects earned between $18.75 and $53.25 with a mean of $38.91, including the training fee. The software implementation of the environment detailed below was programmed at McMaster University using Borland's Delphi programming environment and the MySQL open source database.[3]

Subjects were told that they represented firms which create emissions while producing output and selling it on a simulated market. We chose not to present the experiment in neutral terms, because we believed that

[3]See Appendix A and B posted at http://socserv.mcmaster.ca/econ/mceel/ for the laboratory instructions and screenshots of the computerized environment, respectively.

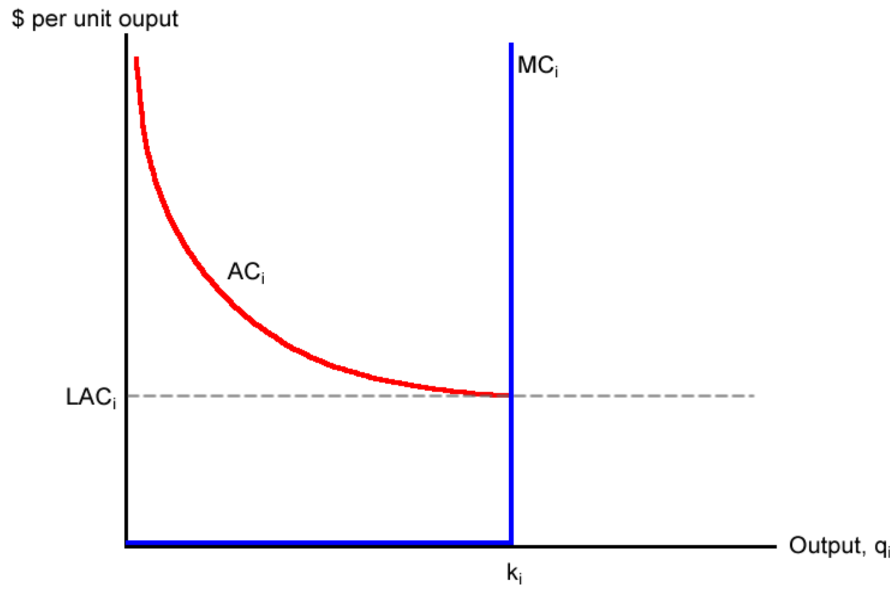

Figure 1: Firm Cost Curves

the explicit emissions trading environment would help subjects understand the nature of the decisions they were making. There were four types of firms distinguished by emission intensity: two, four, six and eight emission units per unit of output for Firm Types A, B, C and D respectively. There were two subjects of each type. Each firm was initially given four units of productive capacity, k. Output could be produced at zero marginal cost up to the fixed capacity. The unit cost of capacity varied from \$32 per unit for the dirtiest firms (Type D) to \$128 per unit for the cleanest firms (Type A). Each firm created external costs proportional to its emissions, although the instructions did not explicitly inform subjects of this. The marginal damage of emissions (not provided to the subjects) was assumed constant at \$16 per unit of emissions. These parameters were chosen to equate the

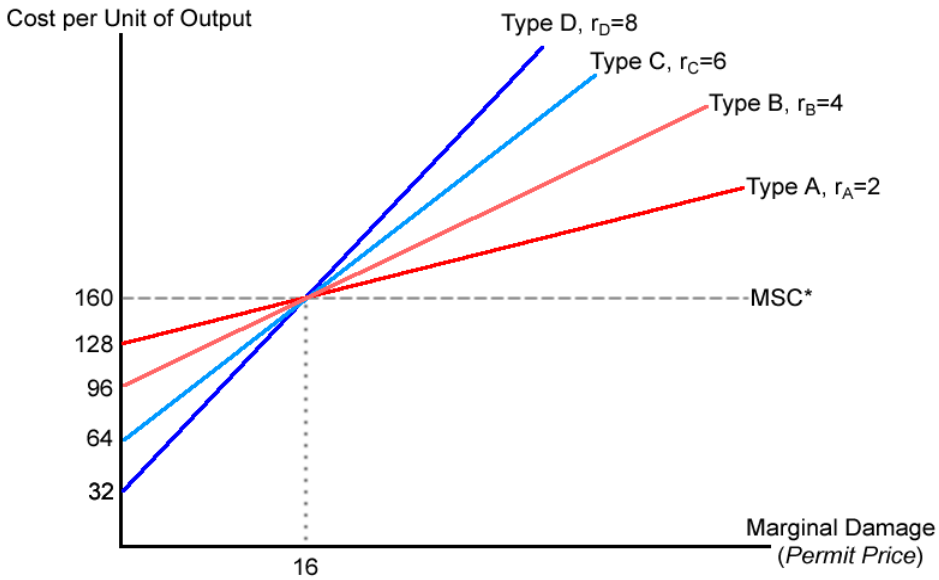

Figure 2: Marginal Social Cost (and *Long-run Average Cost*) by Firm Type

marginal social cost (MSC) of each firm so that all could be present in final equilibrium.[4] Figure 1 illustrates the short- and long-run cost curves for a typical firm and Figure 2 illustrates how the marginal social cost is equated across all firm types when the marginal damage of emissions is equal to $16.

There were two treatments: Cap-and-Trade and Baseline-and-Credit. In both treatments subjects were started off at the cap-and-trade equilibrium, which was chosen to coincide with the social optimum. In the cap-and-trade treatment 160 permits were distributed each period and aggregate production capacity began at 32 units of output. This implies an average emission

[4]Marginal social cost equals unit capacity cost plus the external costs created by each unit of output. For our parameters MSC equals 160 for all four firm types.

intensity of five at the social optimum. We expect the system to remain stable at the equilibrium point. In the baseline-and-credit treatment we imposed a tradable performance standard of 5, equivalent to the average emission intensity in the cap-and-trade treatment. In this treatment we expect the output and emissions to increase due to the inherent subsidy to output.

The treatments differed slightly in the sequence of decisions. A flowchart is provided as Figure 3. In the cap-and-trade treatment subjects begin with capacity and allowance holdings determined in the previous period. They receive an endowment of allowances. Their first action is to trade allowances in a multiple-unit uniform-price sealed bid-ask auction (call market). Subjects were permitted to place up to three bids for additional permits. Each bid was accompanied by a specified number of units. Subjects were also allowed to place up to three asks: each specified a number of units the subject was willing to sell at a specified price. This action required subjects to estimate the price they are willing to pay for additional permits and the price at which they are willing to sell their permits. They were provided with extensive on-screen help to aid them in this decision. Once all bids and asks were submitted, the allowance market cleared, determining a price of permits and a quantity bought or sold for each subject. Each subject was then required to produce and offer for sale as much output as he could, given his capacity and permit holdings. This amount was computed and submitted to the output market automatically. Demand for output was represented by an exogenous demand function with known intercept and slope. The output market then cleared, determining a common output price and an individual quantity sold and revenue earned for each subject. After reviewing their financial report

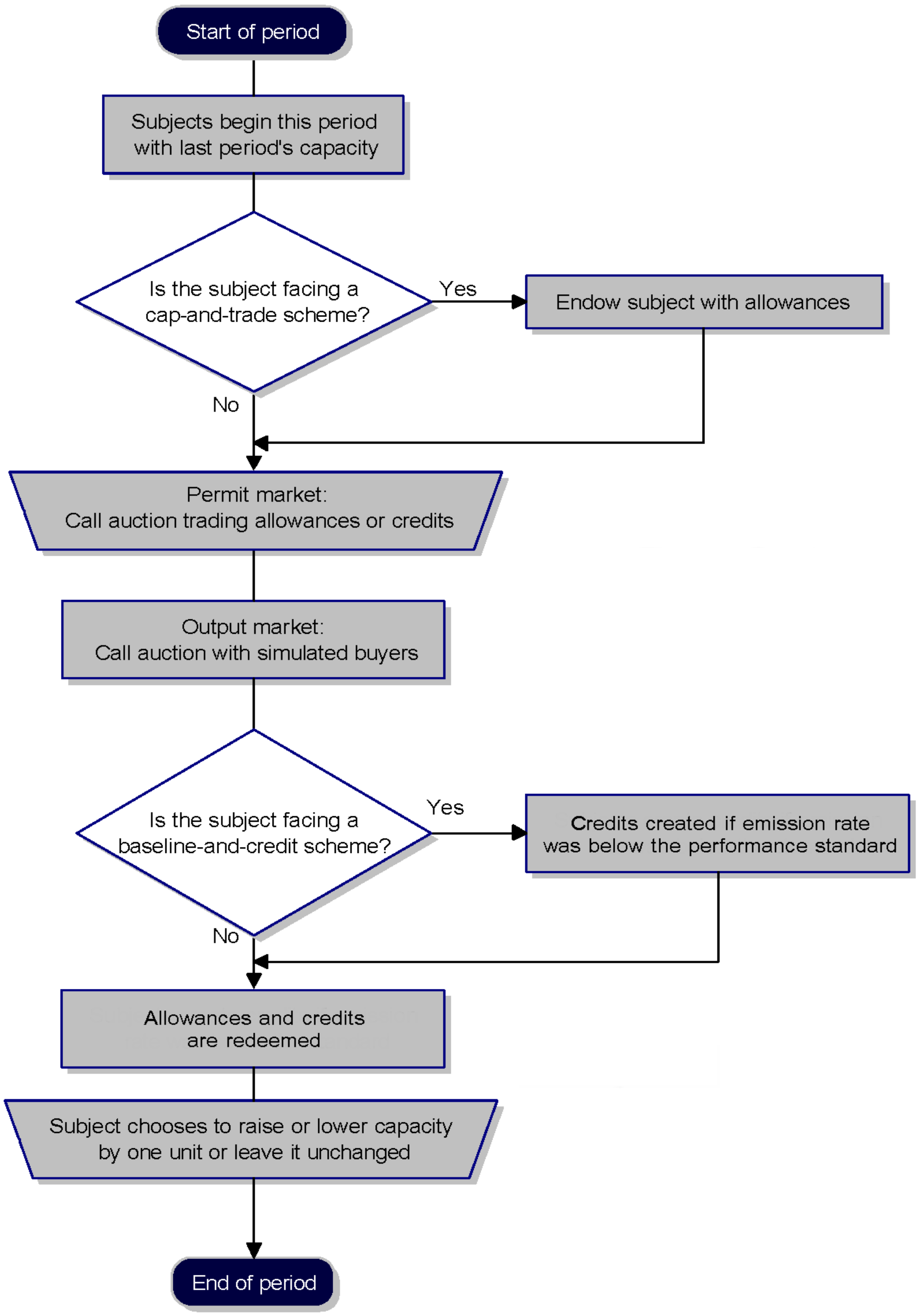

Figure 3: Sequence of Events in a Typical Period

for the period, subjects decide whether to increase or decrease capacity by one unit.

The baseline-and-credit sequence was identical to cap-and-trade except that subjects do not receive any emission permits before the credit market opens. Consequently, they can only trade credits which were produced in previous periods. The quantity of credits created in the current period is determined by the firm's emission intensity and its quantity of output sold, and so were credited after output for the current period was determined.

3 Parameterization and Benchmarks

In this section we derive benchmark equilibria for the two treatments under the assumption of perfect competition. We first introduce some notation and describe the general model which allows adjustment on both the emission intensity and output margins. Secondly we report on the parameterization of the model for this experiment, and finally present the benchmarks.

3.1 Theory

Consider an industry with N firms. Each firm $i \in [1, ..., N]$ produces q_i units of output at an emission rate of $r_i = \frac{e_i}{q_i}$, where e_i is quantity of emissions. Industry output is $Q = \sum_{i=1}^{N} q_i$. Aggregate emissions are $E = \sum_{i=1}^{N} e_i = \sum_{i=1}^{N} r_i q_i$. Environmental damages are assumed to be a positive and weakly convex function of total emissions: $D = D(E)$, $D'(E) > 0$ and $D''(E) \geq 0$. Willingness-to-pay for the output is a weakly concave function of aggregate output, $WTP = \int_0^Q P(z)dz$, where $P = P(Q)$ is an inverse demand curve with positive ordinate ($P(0) > 0$) and negative slope ($P'(Q) < 0$). The private cost of production is a linear homogenous function of output and emissions: $C_i = C_i(q_i, e_i) = q_i C_i(1, r_i)$. Unit cost $C_i(1, r_i)$ can be separated into unit capacity cost $c_i(r_i)$, which is a positive and declining function of the emission rate with $c_i(r_i) > 0$ and $c_i'(r_i) \leq 0$, and unit variable cost w_i, which is a constant function of output. Consequently, total cost is $C_i = c_i(r_i)q_i + w_i q_i$. Note that the marginal cost of output is $c_i(r_i) + w_i$ and the marginal cost of abating pollution is $MAC = -\dfrac{\partial C_i}{\partial e_i} = -c_i'(r_i)$.

An omnipotent social planner would choose an output and emission rate for each firm such that it would maximize total surplus, S. The social planner's welfare maximization problem is

$$\max_{\{r_i, q_i\}} S = \int_0^Q P(z) - \sum_{i=1}^{N} c_i(r_i)q_i - \sum_{i=1}^{N} w_i q_i - D(\sum_{i=1}^{N} r_i q_i) \tag{1}$$

There are two first order conditions, one for each margin of adjustment. They are

$$-c_i' = D'(\sum_{i=1}^{N} r_i{}^* q_i^*) \quad \forall i \in N, \tag{2}$$

and

$$P(Q^*) = c_i(r_i{}^*) + w_i + r_i{}^* D'(\sum_{i=1}^{N} r_i{}^* q_i^*) \quad \forall i \in N, \tag{3}$$

where an asterisk denotes optimal values and it is assumed that $q_i{}^* > 0$ for all i.

The *efficient abatement* condition (2) requires that firms choose emission intensities such that the marginal abatement cost $-c_i'$ equals the marginal damage caused by emissions. The *efficient output* condition (3) ensures that output is surplus-maximizing by requiring each firm's marginal social cost (the right hand side of (3)) equal the marginal willingness to pay for output (the left hand side of (3)). Note that condition (3) determines only the aggregate level of output. Any combination of ${q_i}^*$ such that the ${q_i}^*$s sum to Q^* and the ${r_i}^*{q_i}^*$s sum to E^* satisfies the efficient output condition.[5]

In the present experiment we suppress adjustment on the emission intensity margin by setting each firm's emission intensity to its optimal value r_i^*. Condition (2) vanishes and we are left with condition (3). Because the emissions intensities for each type of firm, r_i, are fixed, firms cannot independently adjust the marginal social cost of their output. For any given marginal damage, $D'(\sum_{i=1}^{N} {r_i}^* q_i^*)$, there will be a set of firm types with least marginal social cost. This set may contain more than one firm type, because two firm types can have identical marginal social cost if the reduced social damage generated by the clean firm type is exactly offset by an increase in private cost.

The social optimum can be supported as a competitive equilibrium under cap-and-trade regulation. The regulator distributes allowances A_i to each firm so that the sum of allowances granted equals the optimal level of emissions, that is, $\sum_{i=1}^{N} A_i = E^*$. Letting P_c denote the price of permits under cap-and-trade, firm i's profit maximization problem is

$$\max_{\{q_i\}} \pi_i^c = P(Q)q_i - c_i({r_i}^*)q_i - w_i q_i - P_c({r_i}^* q_i - A_i). \tag{4}$$

The first order condition for an interior maximum is

$$P(Q^c) = c_i({r_i}^*) + w_i + {r_i}^* P_c. \tag{5}$$

[5]This feature of the model is a direct result of the constant marginal cost of output assumption. Unit cost, $c_i({r_i}^*)$, is a function of emission rate but not output. If this assumption were relaxed, condition (3) would imply a firm specific output level but would result in a more complicated laboratory environment.

Equation (5) requires that each firm earn zero marginal profit, and identifies Q^c. Because equation (5) can be obtained from equation (3) by replacing $D'(\sum_{i=1}^{N} r_i^* q_i^*)$ by P_c and Q_i^* by Q_i^c, a solution to the surplus maximization problem is a competitive equilibrium and vice versa.

Under a baseline-and-credit plan, the regulator sets an industry-wide performance standard, r^s. Firm i's demand for credits is $({r_i}^* - r^s)q_i$. Negative values denote a supply of credits. If the price of credits is P_b, then firm i's profit maximization problem is

$$\max_{\{q_i\}} \pi_i^b = P(Q)q_i - c_i({r_i}^*)q_i - w_i q_i - P_b q_i({r_i}^* - r^s) \tag{6}$$

The first order condition for an interior maximum is

$$P(Q^b) = c_i({r_i}^*) + w_i + {r_i}^* P_b - r^s P_b. \tag{7}$$

Equation (7) is the zero marginal profit condition which determines Q^b. Let us assume that the regulator sets the emission rate standard equal to the average emission rate under the social planner scenario, $r^s = (\sum_{i=1}^{N} r_i^* q_i^*)/Q^*$.[6] Comparing the baseline-and-credit condition (7) to the cap-and-trade condition (5), we immediately see that the latter differs from the former only in the last term, $-r^s P_b$, which acts as an output subsidy to the firm. Consequently, marginal private cost to the firm is less than the marginal social cost and the corresponding output, Q^b, will be higher than under cap-and-trade. Since the equilibrium of both trading plans involve the same average

[6]As mentioned in section 1, we will find that setting the performance standard equal to the optimal average emission rate will result in quantities of emissions and output that are inefficiently high. We could set a stricter standard so that quantities of output and emissions are optimal but then firm costs will be inefficiently high. Considering that both methods yield inefficiency we choose to focus on the case comparing cap-and-trade with a baseline-and-credit system with a performance standard equal to the average emission rate from the optimal scenario.

Table 1: Cost Parameters

Firm Type	Unit Fixed Cost $c_i(r_i{}^*)$	Fixed Emission Rate	Endowment	Performance Standard	B&C Initial Credits
A	128	2	20	5	12
B	96	4	20	5	4
C	64	6	20	5	0
D	32	8	20	5	0

Table 2: Variable Capacity Predictions

Trading Institution	Price of Allowances or Credits	Output Price	Aggregate Output	Aggregate Emissions	Active Firm Types
B&C	16	80	48	240	A,B,C,D
C&T	16	160	32	160	A,B,C,D

Note: B&C is Baseline-and-Credit and C&T is Cap-and-Trade.

emission ratio, this higher level of output necessarily implies that aggregate emissions will be higher than optimal under baseline-and-credit regulation.

3.2 Parameterization

Table 1 presents firm-specific parameters used in the sessions reported in this paper. Table 2 summarizes the associated equilibrium predictions under the alternative emission trading mechanisms. It is useful to illustrate the equilibria diagrammatically.

Figure 4 illustrates the cap-and-trade equilibrium when only type A and D firms are in the market. The dirty firms have long-run average costs (LAC)

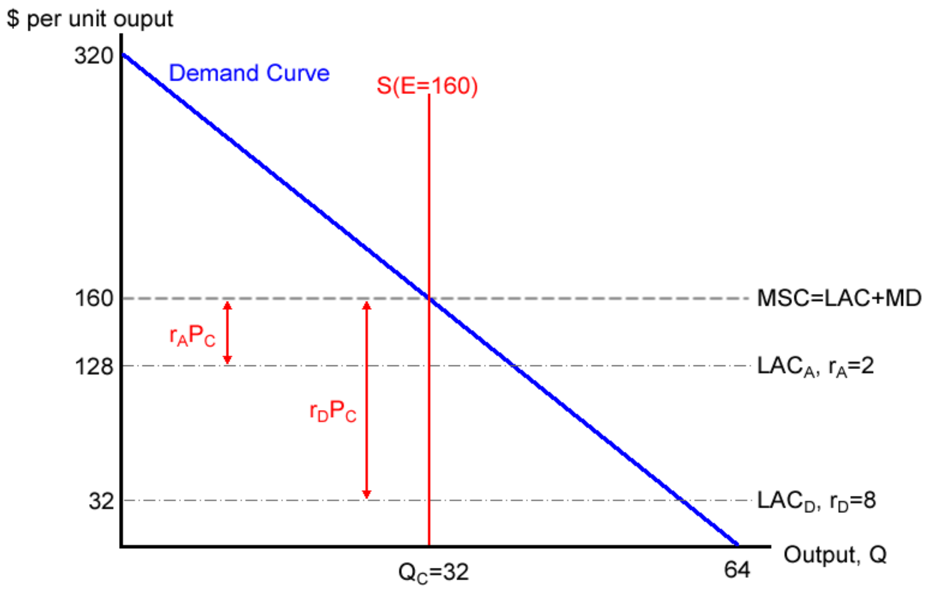

Figure 4: Cap-and-Trade Equilibrium

of 32 and create damages of $r_D MD = 8 \times 16 = 128$ per unit of output. Marginal social cost is 160. Firm type A has a higher unit capacity cost at \$128 but lower damages of $r_A MD = 2 \times 16 = 32$ per unit of output, yielding the same marginal social cost. Optimal output $Q_C^* = 32$ is determined by the intersection of the demand curve and marginal social cost. At the optimal output, type A firms earn $160 - 128 = 32$ in rent per unit of output, or $32/2 = 16$ per unit of emissions. Type D firms earn $160 - 32 = 128$ in rent per unit output, or $128/8 = 16$ per unit of emissions. Both types of firms are willing to pay \$16 per permit. Under cap-and-trade, the regulatory authority allocates 160 allowances and the allowance market clears at \$16 per permit. Long-run average cost is now \$160 for each firm type. Equilibrium at a price of \$160 implies output of 32 units, and an average emission intensity

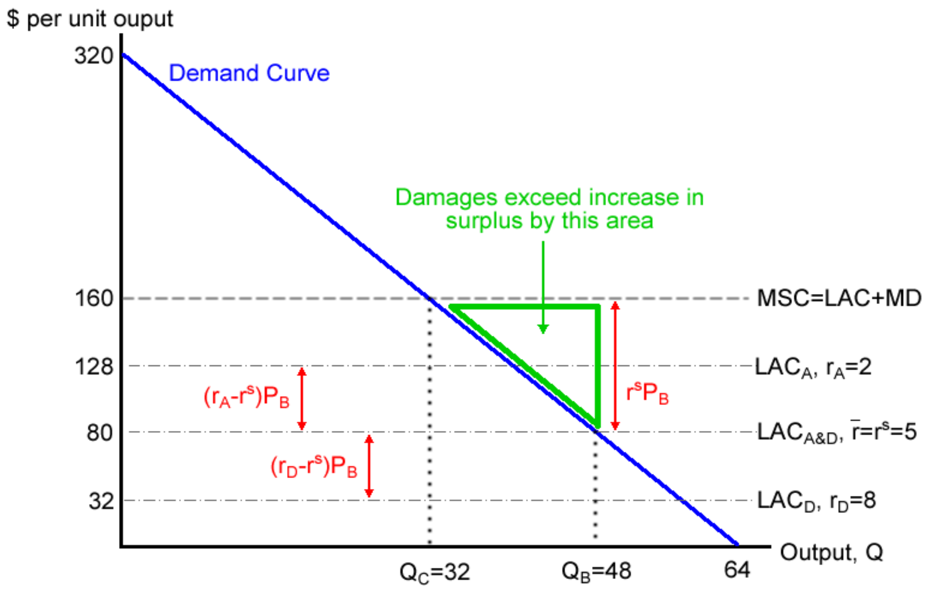

Figure 5: Baseline-and-Credit Equilibrium

of 5. The only way to achieve an average emission intensity of 5 with type A ($r_A = 2$) and D ($r_D = 8$) firms is to have equal output capacity of each firm type. This equilibrium implies the presence of 16 units of capacity from type A and 16 units of capacity of type D in the market.

Figure 5 shows the equivalent baseline-and-credit equilibrium. The performance standard is $r^s = 5$ units of emissions per unit of output. Restricting attention to type A and D firms, we see this implies that there must be equal capacity of each firm type. The effect of baseline-and-credit trading is to equate the LAC of both firm types. Given equal capacity shares, average $LAC = (128 + 32)/2 = 80$. This determines the inefficient equilibrium output of 48 units, 24 from each firm type. At this point, type D firms must buy $r_D - r^s = 3$ credits per unit of output and they are willing to pay

$(80-32)/3 = 16$ per credit. Type A firms create $r^s - r_A = 3$ credits per unit of output. They must receive at least $(128-80)/3 = 16$ per credit to earn non-negative profits under baseline-and-credit. Since there is equal capacity of type A and D firms (24 units for each type), the supply of credits equals demand for credits at a price of \$16.

3.3 Efficiency

We compute the efficiency of baseline-and-credit and cap-and-trade equilibria relative to the maximum surplus available. The social surplus is equal to the sum of consumers' surplus and producers' surplus less any environmental damage. In computing the environmental damages we assume constant marginal damages of \$16 per unit of emissions. From Figure 4 it is clear that under cap-and-trade consumers' surplus in equilibrium is $0.5(320-160)(32) = \$2560$. Producers' Surplus is $(160-80)(32) = \$2560$, the same amount. External damages are equal to total emissions multiplied by the marginal damage, $160 \times 16 = 2560$. Note that this exactly offsets the producers' surplus, so that total social surplus is equal to the consumer surplus of \$2560. Because the emissions cap was set to the socially optimal level of 160 units of emissions, the cap-and-trade surplus values are optimal. Using Figure 5, the corresponding consumers' surplus, producers' surplus, external damages and total social surplus under baseline-and-credit are \$5760, \$0, \$3840 and \$1920, respectively.

Given these definitions we can compute an efficiency index

$$\text{Efficiency} = \frac{\text{Actual Total Surplus}}{\text{Optimal Total Surplus}}. \tag{8}$$

It is convenient to decompose efficiency into components associated with

Table 3: Equilibrium Surplus and Efficiency

		Components of Efficiency		
	Efficiency	Consumer Surplus	Producer Surplus	Environmental Damages
	=	+	+	-
Cap-and-Trade Equilibrium:				
C&T Surplus	\$2560	\$2560	\$2560	\$2560
Efficiency Index	100%	100%	100%	100%
Baseline-and-Credit Equilibrium:				
B&C Surplus	\$1920	\$5760	\$0	\$3840
Efficiency Index	75%	225%	0%	150%

Note: B&C is Baseline-and-Credit and C&T is Cap-and-Trade.

consumer surplus, producer surplus and external costs. Thus the consumer surplus component of the efficiency index is

$$\text{Consumer Surplus Component} = \frac{\text{Actual Consumer Surplus}}{\text{Optimal Total Surplus}}. \tag{9}$$

Table 3 reports the equilibrium values for total surplus and its components under the two treatments.

4 Results

Figures 6 to 11 provide an overview of the data. We have three independent series in each treatment. The figures show the range and mean of observations for each period. Many series show a distinct time trend. Moreover, the fact that there was no payoff to subjects' inventory of permits held at the end of the session may have induced an end-game effect in Period 10.

Table 4: Mean Values over Period 6 to 9 by Treatment

	Capacity*	Output Volume*	Aggregate Emissions*	Permit Market Price	Permit Market Volume	Permit Inventories*
Cap-and-Trade:						
Session 1	36.50	33.50	159.50	14.75	30.75	17.50
Session 2	34.50	34.25	157.50	7.00	31.25	69.50
Session 3	38.75	30.00	163.00	23.25	46.75	10.50
Treatment Mean	36.58	32.58	160.00	15.00	36.25	32.50
Prediction	32.00	32.00b	160.00b	16.00	32.00b	0.00b
Baseline-and-Credit:						
Session 4	48.25	47.00	212.00	11.50	46.00	106.25
Session 5	51.00	49.75	218.00	10.75	45.50	142.50
Session 6	45.25	45.25	217.50	6.50	50.50	119.00
Treatment Mean	48.17	47.33	215.83	9.58	47.33	122.58
Prediction	48.00	48.00c	240.00cb	16.00	48.00c	0.00b

* Treatment effect is significant using a t-test and a Mann-Whitney U-test at a 5% critical level.

c The cap-and-trade treatment is significantly different from the prediction using a t-test at the 5% level.

b The baseline-and-credit treatment is significantly different from the prediction using a t-test at the 5% level.

Accordingly we drop Periods 1 through 5 and 10 in summarizing the results numerically and report mean values for Periods 6 through 9 in Table 4. We test for treatment effects using parametric (F-test) and non-parametric methods. However these tests have extremely limited power, even adopting a critical level of 10%, so they should not be taken too seriously.[7]

[7] With a critical level of 10% there is about a 45% chance of detecting a true difference in means of 1.5 standard deviations. We would need a critical level of 25% to get a 70% chance of detecting this large a difference in means (two-tailed tests, common variance).

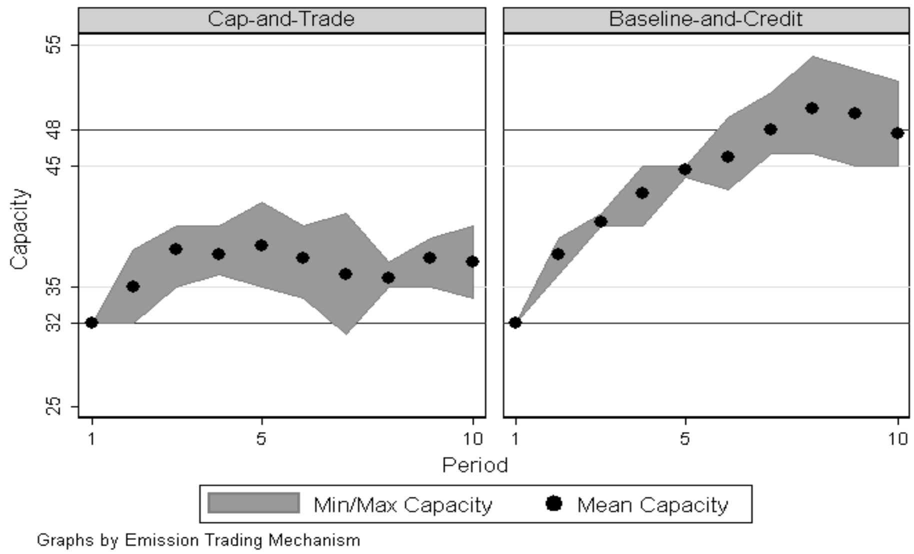

Figure 6: Capacity

4.1 Capacity, Output and Emissions

Consider first the key predictions on capacity, output and emissions. Figure 6 shows the evolution of capacity. Under baseline-and-credit trading, capacity rises steadily to reach the predicted level of 48 by period 7. Under cap-and-trade capacity stabilizes quickly between 36 and 40, significantly above the benchmark of 32. The treatment effect is strongly significant. Figure 7 shows a similar pattern for output, except that under cap-and-trade output exceeds the benchmark level of 32 by only a small amount. This suggests pervasive underutilization of capacity due to inability to acquire permits. Emissions (Figure 8) follow the same pattern as output. Despite the general

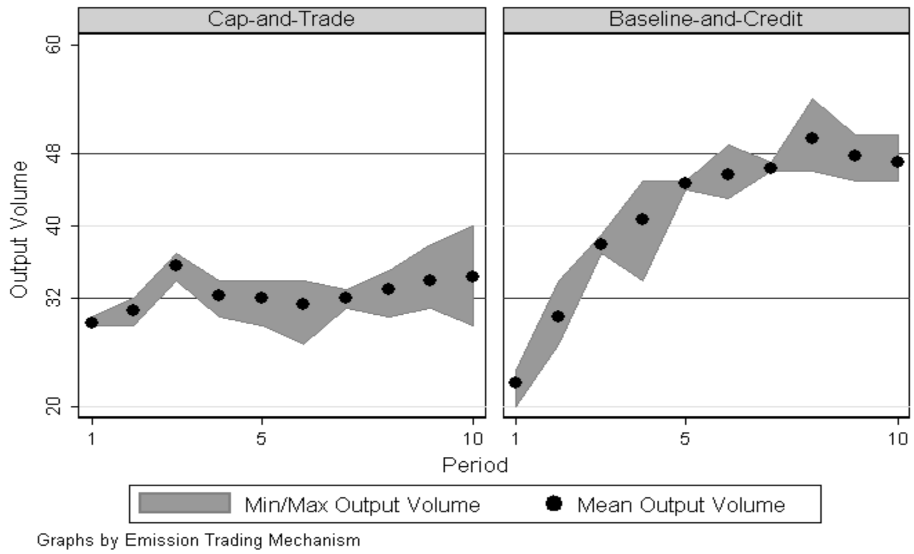

Figure 7: Output Volume

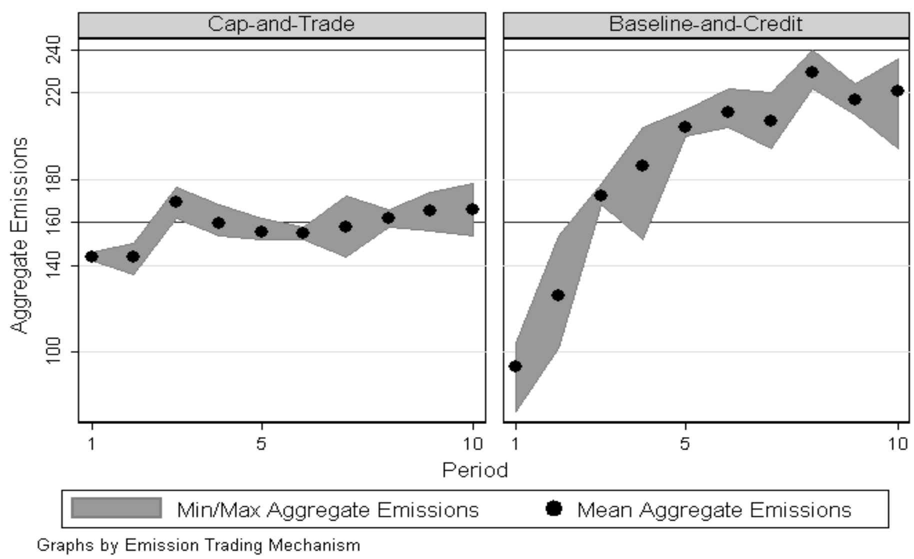

Figure 8: Aggregate Emissions

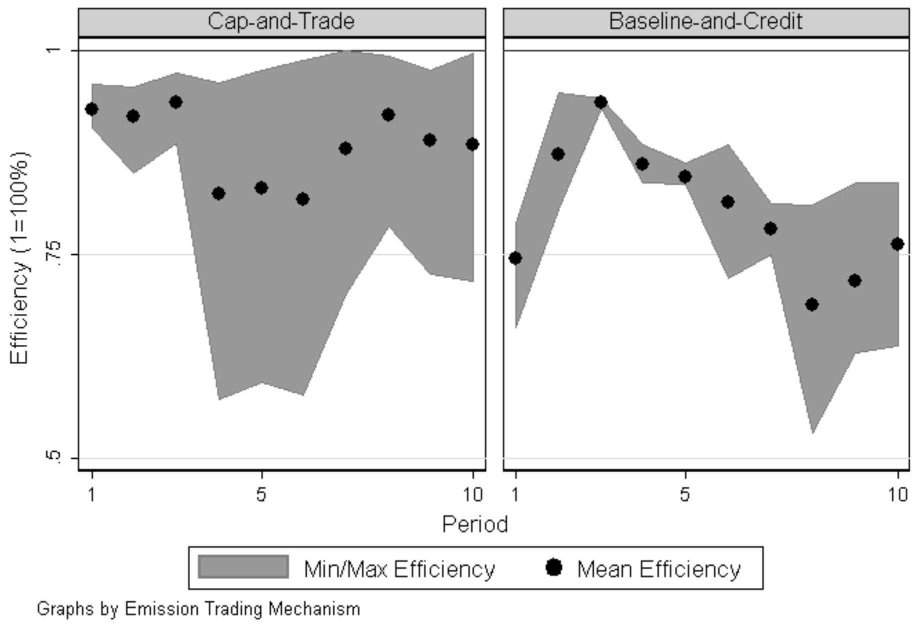

Figure 9: Efficiency

resemblance to the benchmarks, both treatments deviate significantly from their own benchmark equilibria. Nevertheless the treatment effect (cap-and-trade vs. baseline-and-credit) is strongly significant. In total, these observations conform well to the underlying theory.

These results imply that the efficiency losses from baseline-and-credit trading will be similar to those predicted by theory. Figure 9 reports the evolution of efficiency over the ten periods. Table 5 reports the numerical results. Efficiency was highly variable across sessions. Two of the cap-and-trade sessions attained close to 100% efficiency, while the third achieved only 70%. Mean efficiency in the three cap-and-trade sessions was almost exactly the predicted level of 75%. Due to the wide variation the difference in means

Table 5: Mean Efficiency over Periods 6 to 9

		Components of Efficiency		
	Efficiency	Consumer Surplus*	Producer Surplus*	Environmental Damages*
	=	+	+	-
Cap-and-Trade:				
Session 1	95%	109%	85%	99%
Session 2	99%	115%	82%	98%
Session 3	70%	88%	83%	101%
Treatment Mean	88%	104%	83%	100%
C&T Equilibrium	100%	100%	100%	100%
Baseline-and-Credit:				
Session 4	75%	215%	-8%	132%
Session 5	67%	243%	-39%	136%
Session 6	83%	199%	19%	135%
Treatment Mean	75%	219%	-9%	134%b
B&C Equilibrium	75%	225%	0%	150%

* Treatment effect is significant using a t-test and a Mann-Whitney U-test at a 5% critical level.

b The baseline-and-credit treatment is significantly different from the prediction using a t-test at the 5% level.

was not significant. Treatment effects were significant for each of the three components of surplus, however. Under cap-and-trade consumer surplus and damage were close to their benchmark values, while producer surplus was significantly lower, suggesting that costs were not being minimized. Under baseline-and-credit trading consumer and producer surplus were close to the benchmarks while emission damage was less than expected, although still higher than in the cap-and-trade treatment.

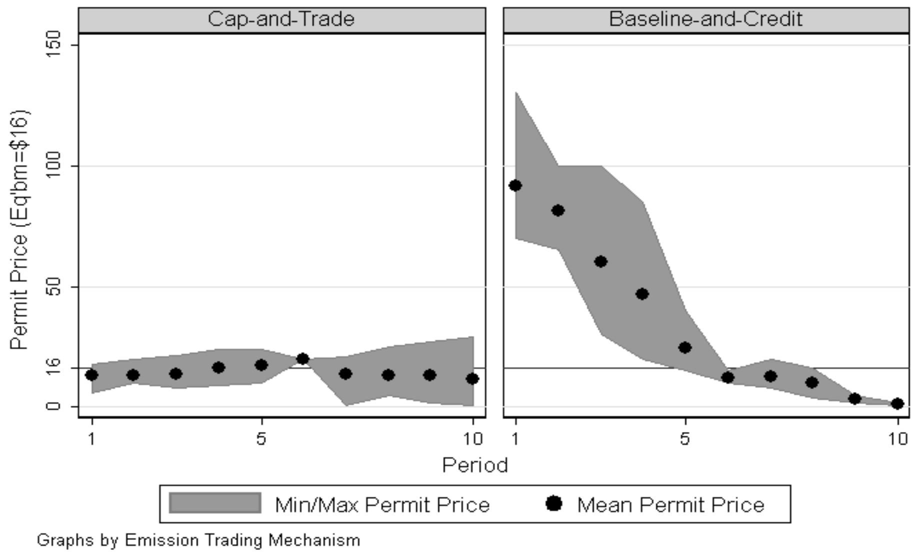

Figure 10: Permit Trading Prices

4.2 Credit and Allowance Markets

The relatively promising results discussed above were obtained despite some rather strange behaviour in the markets for credits and allowances. Figure 10 shows dramatic differences in permit prices across treatments. In cap-and-trade permit prices are consistently very close to the benchmark and not significantly different from it. In baseline-and-credit, credit prices start very high, then fall rapidly to below equilibrium levels. However the two series are not significantly different in periods 6 through 9. The high early prices and rapid decline of permit prices under baseline-and-credit is probably due to bidding errors in the early periods of the session. A similar pattern was observed in Buckley (2004), leading to the supposition that it is an institutional factor associated with baseline-and-credit plans that is driving

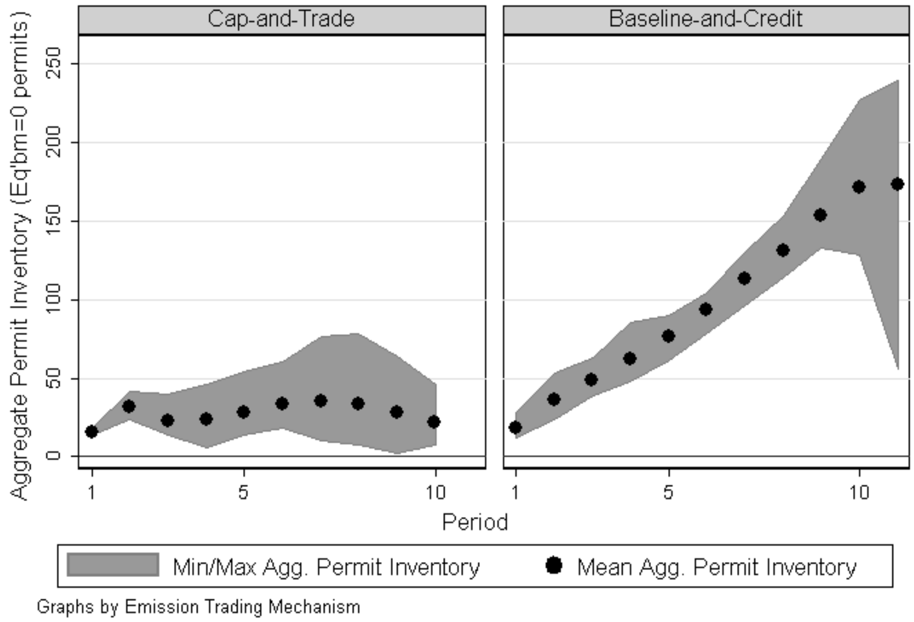

Figure 11: Aggregate Inventory

the differences. One such factor is the requirement that credits be generated before being offered for sale.

One quite dramatic difference between baseline-and-credit and cap-and-trade plans lies in the behaviour of permit inventories, as illustrated in Figure 11. In the present experiment, any inventory of permits at the end of the experiment is irrational. Both treatments exhibit significant inventory build-ups, but while the cap-and-trade inventories stabilize below 50 baseline-and-credit inventories climb steadily. These differences are driven by the increased supply of credits generated by expanded output under the fixed performance standard of baseline-and-credit regulation. The supply of permits is fixed under cap-and-trade regulation.

5 Discussion and Conclusions

Theory predicts higher aggregate output and emission under baseline-and-credit than under cap-and-trade when the former imposes a performance standard consistent with the cap under the latter plan. This is because a performance standard acts as a subsidy on output. The question remained, however, whether the theoretical predictions regarding the two mechanisms would hold in real markets. This paper reports results on controlled laboratory sessions in an environment involving fixed emission technologies and variable output capacities.

Results from the experimental sessions reported here support the theory. Using graphical and tabular data, we have confirmed that, while cap-and-trade emission and output levels stay close to their predicted equilibrium values, emissions and output soar and converge to their predicted higher levels under baseline-and-credit. Despite differences in early permit trading prices under the two plans, the results strongly support the theoretical predictions.

One caveat, however, is that it appears that baseline-and-credit regulation is susceptible to higher levels of permit inventories than cap-and-trade. Even though permits inventories are predicted to be zero in the baseline-and-credit equilibrium evidence shows that permits are accumulated in inventory over the entire experiment. This behaviour might be caused by the relatively more complex framing of the baseline-and-credit institution in addition to the variable permit supply inherent to baseline-and-credit regulation.

An experimental environment has now been designed and tested. This paper reports sessions involving fixed emission rate and variable capacity while Buckley (2004) provides results from sessions assuming fixed output capacity and variable emission rates. With the theoretical framework and corresponding experimental environment in place, future work can now assess the long-run theoretical prediction of higher output and emissions under baseline-and-credit trading in a full model in which firms choose emission rates and output capacities.

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